United States Department of Agriculture | Natural Resources Conservation Service | 5 Radnor Corporate Center, Suite 200
100 Matsonford Road
Radnor, PA 19087-4585

Subject: SOI-Electromagnetic Induction (EMI) Field Training **Date:** 1 September 1999

To: John Titchner
State Conservationist
USDA - NRCS
69 Union Street
Winooski, Vermont 05404

M. Darrel Dominick
State Conservationist
USDA-NRCS
5 Godfrey Drive
Orono, ME 04473-1100

Purpose:
To provide training on the operation and use of electromagnetic induction (EMI) meters. Two EM meters, an EM38 (Serial # 8906008) and EM31 (Serial # 8906013) were loaned to Lisa Krall for use in New England.

Participants:
Jim Doolittle, Research Soil Scientist, USDA-NRCS, Radnor, PA
Phoebe Hardesty, Conservationist, Androscoggin Valley SWCD, Lewiston, ME
Lisa Krall, Agronomist (IRTS), USDA-NRCS, Orono, ME
Laura Lecker, Conservationist, Oxford County SWCD, Oxford, ME
Ron Olson, Soil Resource Specialist, USDA-NRCS, Bangor, ME
Kip Potter, Environmental Specialist, USDA-NRCS, Winooski, VT
Rose Mary Seymour, Professor of Bio-Resource Engineering, Univ. of Maine, Orono, ME
Jim Turenne, Soil Scientist (GPR), USDA-NRCS, West Wareham, Massachusetts
Tom Villars, Soil Resource Specialist, USDA-NRCS, White River Junction, VT
Dave Wilkinson, Resource Soil Scientist, USDA-NRCS, Lewiston, ME

Activities:
All activities were completed during the period of 23 to 26 August 1999. An EM31 meter was picked-up at the NRCS State Office in Storrs, Connecticut, on the morning of 23 August. Later that morning, the manufacturer made modifications to a SIR2000 radar unit in North Salem, New Hampshire. On 24 August, training was provided to NRCS staff personnel from Massachusetts and Vermont at the Pollard Farm near Guilford, Vermont. August 25 was a day of travel. On 26 August, training was provided to NRCS staff personnel from Maine at the Wolfe's Neck Farm near Freeport, Maine.

Equipment:
The electromagnetic induction meters used in this study were the EM38 and the EM31 manufactured by Geonics Limited.[1] These meters are portable and require only one person to operate. McNeill (1980) and Geonics Limited (1998) have described principles of operation for the EM31 and the EM38 meters, respectively. No ground contact is required with these meters. These meters provide limited vertical resolution and depth information. Lateral resolution is approximately equal to the intercoil spacing. The EM38 meter operates at a frequency of 14,800 Hz. It has theoretical observation depths of about 0.75 and 1.5 meters in the horizontal and vertical dipole orientations, respectively (Geonics Limited, 1998). The EM31 meter operates at a frequency of 9,810 Hz. It has theoretical observation depths of about 3.0 and 6.0 meters in the horizontal and vertical dipole orientations, respectively (McNeill, 1980). Values of apparent conductivity are expressed in milliSiemens per meter (mS/m).

[1] Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.

To help summarize the results of this study, the SURFER for Windows program, developed by Golden Software, Inc.,[2] was used to construct three- and two-dimensional simulations. Grids were created using kriging methods with an octant search.

Results:

1. Participants received training on the use and operation of the EM38 and the EM31 meters. At each training site, systematic field surveys were completed with each meter. Data were interpreted in the field.

2. Electromagnetic induction is suited to surface and ground water contamination studies. This method can provide in a relatively short time the large number of observations that are needed to comprehensively cover sites. Maps prepared from correctly interpreted EMI data provide the basis for assessing site conditions and for planning further investigations.

3. The results of the EMI survey at the site in Vermont suggest limited seepage from a concrete outlet of a waste-holding tank. A zone of higher apparent conductivity values is distinguishable in a down slope direction for about 75 ft from this outlet. Two more conspicuous patterns of anomalously high apparent conductivity values were associated with an exposed and open drain from a nearby septic field and runoff from an animal waste stacking area.

4. The results of the EMI survey at the site in Maine do not indicate contamination of a drainageway by waste products from the animal-waste stacking area.

5. Geophysical interpretations are considered preliminary estimates of site conditions. The results of geophysical site investigations do not substitute for direct observations, but rather reduce their number, direct their placement, and supplement their interpretations. Interpretations contained in this report should be verified by ground-truth observations.

6. Lisa Krall is commended for her leadership and excellent organization of this field training session.

It was my pleasure to work again in Vermont and Maine and with members of your fine staffs.

With kind regards,

James A. Doolittle
Research Soil Scientist

cc:
J. Culver, Director, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
L. Krall, Agronomist IRTS, USDA-NRCS, 5 Godfrey Drive, Orono, ME 04473-1100
W. Nettleton, National Leader, Soil Investigation Staff, USDA-NRCS, National Soil Survey Center, Federal Building, Room 152,100 Centennial Mall North, Lincoln, NE 68508-3866
H. Smith, Director of Soils Survey Division, USDA-NRCS, Room 4250 South Building, 14th & Independence Ave. SW, Washington, DC 20250
B. Thompson, State Soil Scientist/MLRA Office Leader, USDA-NRCS, 451 West Street, Amherst, MA 01002

[2] Trade names have been used in this report to provide specific information. Their use does not constitute endorsement.

Electromagnetic Induction

Electromagnetic induction is a noninvasive geophysical tool that uses electromagnetic energy to measure the bulk electrical conductivity of soil below the transmitter and receiver coils. This apparent conductivity (EC_a) is a weighted, average conductivity measurement for a column of earthen materials to a specific observation depth (Greenhouse and Slaine, 1983). Variations in apparent conductivity are produced by changes in the electrical conductivity of soils. The electrical conductivity of soils is influenced by the types and concentration of ions in solution, the amount and types of clays in the soil matrix, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). The apparent conductivity of soils increases with increases in soluble salts, water, and clay contents (Kachanoski et al., 1988, Rhoades et al., 1976).

Electromagnetic induction has been used to investigate the seepage of contaminants from waste sites (Brune and Doolittle, 1990, Drommerhausen, 1995, Eigenberg et al., 1998, Radcliffe et al., 1994, Ranjan and Karthigesu, 1995, Siegrist and Hargett, 1989, and Stierman and Ruedisili, 1988). Soils affected by animal wastes have higher apparent conductivity values than adjoining soils that are unaffected by these contaminants. Electromagnetic induction has been used to infer the relative concentration, extent, and movement of contaminants from waste-holding facilities. Electromagnetic induction does not provide a direct measurement of specific ions or compounds. However, measurements of apparent conductivity have been correlated with specific ions that are mobile in the soil and associated with animal wastes. Apparent conductivity has been correlated with concentrations of chloride, ammonia, and nitrate nitrogen in soils (Brune and Doolittle, 1990, Ranjan and Karthigesu, 1995, Eigenberg et al., 1998).

Vermont Study Site

The site is located in Windham County about 1-mile southeast of Guilford. The site was in pasturage and extended down slope from several barns and an animal waste stacking area. A concrete outlet for a subsurface waste-holding tank and drain field was located along the upper slope break. The tank contained acid-washed, milk parlor wastes and was overflowing. The drain field was clogged.

The study site is located in an area that has been mapped as Fullam silt loam, 8 to 15 percent slopes, and Walpole fine sandy loam (Sheeham, 1987). The very deep Fullam soil is moderately deep over a densic contact. This moderately well drained soil formed in dense loamy tills on glaciated uplands. Fullam soil is a member of the coarse-loamy, mixed, active, frigid Aquic Dystrudepts family. The very deep, poorly drained Walpole soil formed in outwash and stratified drift on stream terraces. Walpole soil is a member of the sandy, mixed, mesic Aeric Endoaquepts family.

Field Procedures:

An irregularly shaped, 150 by 150-foot grid was established on the western and downslope side of dairy barns and a concrete-floored, waste-stacking area. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation point. This procedure provided 44 observation points.

The relative elevation of each observation point was determined with a level and stadia rod. Elevations were not tied to a benchmark; the lowest measured ground surface served as the 0.0-foot datum. Figure 1 is a three-dimensional surface net diagram of the study area. Relief is about 38.5 feet. A small stream that crosses the extreme southwestern corner of the study site is shown in Figure 1. Also shown in Figure 1 are the locations of the observation points and the outlet for the waste-holding tank.

Measurements were taken at each observation point with an EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations. Measurements were taken at each observation point with an EM31 meter held at hip-height in both the horizontal and vertical dipole orientations.

Results:

Table 1 summarizes the apparent conductivity measurements. In general, values of apparent conductivity were low and invariable across most of the study site. The apparent conductivity of the upper 0.75 meter (measured with the EM38 meter in the horizontal dipole orientation) averaged 11.3 mS/m with a range of –36.0 to 57.0 mS/m. One-half of the observations had values of apparent conductivity between 5.4 and 14.0 mS/m. The apparent conductivity of the upper 1.5 meters (measured with the EM38 meter in the vertical dipole orientation) averaged 11.0 mS/m with a range of 3.0 to 5.4 mS/m. One-half of the observations had values of apparent conductivity between 6.0 and 11.3 mS/m. The more variable measurements recorded with the EM38 meter in the horizontal dipole orientation are presumed to represent interference from small metallic artifacts detected in the near surface layers.

The apparent conductivity of the upper 2 meters (measured with the EM31meter held at hip-height in the horizontal dipole orientation) averaged 8.8 mS/m with a range of 5.0 to 9.5 mS/m. One-half of the observations had values of apparent conductivity between 7.0 and 8.6 mS/m. The apparent conductivity of the upper 5 meters (measured with the EM31 meter held at hip-height in

the vertical dipole orientation) averaged 10.2 mS/m with a range of 6.5 to 14.0mS/m. One-half of the observations had values of apparent conductivity between 7.4 and 10.6 mS/m.

Table 1
Basic Statistics
EMI Survey
Guilford, Vermont, Study Site
(All values are in mS/m)

	AVERAGE	MINIMUM	MAXIMUM	FIRST	MEDIAN	THIRD
EM38H	11.3	-36.0	57.0	5.4	9.5	14.0
EM38V	11.0	3.0	5.4	6.0	8.0	11.3
EM31H	8.8	5.0	9.5	7.0	7.5	8.6
EM31V	10.2	6.5	14.0	7.4	9.0	10.6

Figure 2 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the EM38 meter. The upper plot represents data collected with the EM38 meter in the horizontal dipole orientation. The lower plot represents data collected with the EM38 meter in the vertical dipole orientation. The location of the outlet for the waste-holding tank has been shown in each plot. In each plot, the isoline interval is 4 mS/m.

Anomalous values (see "A" and "B" in Figure 2) in both plots are presumed to represent interference from small metallic artifacts buried in the near surface layers. Because of their high negative and positive apparent conductivity values, these anomalies have disrupted and masked other spatial patterns in these plots and influenced the isoline interval. To make these other spatial patterns more evident, the two anomalous values were removed from the data set and three additional observation points were added to the data set. The added observation points were located immediately down slope of the outlet for the waste-holding tank in a seepage area. The revised plots are shown in Figure 3.

In Figure 3, the upper plot represents data collected with the EM38 meter in the horizontal dipole orientation. The lower plot represents data collected with the EM38 meter in the vertical dipole orientation. The location of the outlet for the waste-holding tank has been shown in each plot. In each of these plots, the isoline interval is 2 mS/m.

In both plots of Figure 3, a plume-like pattern is evident near the outlet for the waste-holding tank. However, the pattern is restricted in spatial extent (about 75 ft). Two conspicuous areas (near "A" and "B") of high apparent conductivity are evident in both plots. Within these anomalous areas, values of apparent conductivity obtained with the shallower sensing horizontal dipole orientation are higher than values obtained with the deeper-sensing vertical dipole orientation. This relationship suggests the presence of more conductive materials in the surface layers. An exposed drain from a nearby septic drain field is located adjacent to "A." Wastes from this system are believed to be responsible for the area of high conductivity that extends down slope (towards the lower boundary of the survey site) from "A." As waste are being deposited on the surface, values of apparent conductivity would be higher in the surface layers and decrease with depth (measurements greater in the horizontal than in the vertical dipole orientation). The landowner reported the removal of large amounts of animal wastes from a concrete floored stacking area during a period of heavy rains. The stacking area is located near the upper right-hand corner of each plot. The deposition of wastes carried by runoff is believed to be responsible for the pattern of high apparent conductivity values near "B." Once again, as waste products have been deposited on the surface, values of apparent conductivity would be higher in the surface layers and decrease with depth (measurements greater in the horizontal than in the vertical dipole orientation).

Figure 4 contains two-dimensional plots showing the spatial distribution of apparent conductivity collected with the EM31 meter. The upper plot represents data collected with the EM31 meter in the horizontal dipole orientation. The lower plot represents data collected with the EM31 meter in the vertical dipole orientation. The location of the outlet for the waste-holding tank has been shown in each plot. In each of these plots, the isoline interval is 2 mS/m.

In Figure 4, no plume-like pattern is evident near the outlet for the waste-holding tank. If seepage of waste products has occurred at the outlet, it is not detectable with this meter. Once again, two conspicuous areas (near "A" and "B") of high apparent conductivity are evident in both plots. The exposed drain from the septic drain field is believed to be responsible for the elevated apparent conductivity values near "A." The deposition of waste products from surface runoff is believed to be responsible for the pattern of high apparent conductivity values near "B."

Figure 5 provides a different representation of the data collected with the EM38 meter. Figure 5 contains two-dimensional plots showing the distribution of apparent conductivity overlaid on two, three-dimensional surface plots of the study site. In each plot, the isoline interval is 2 mS/m. These plots may help to better visualize the relationship of apparent conductivity patterns with the landscape. An area of higher apparent conductivity values appears to emanate from outlet of the waste-holding tank and to extend down slope from the structure for at least 75 feet. Higher values of apparent conductivity within this plume-like area may be caused by higher concentrations of soluble salts and water.

The results of the EMI survey at this site suggest that seepage from a concrete outlet of a waste-holding tank is extending about 75 feet down slope in a plume-like pattern. A zone of higher apparent conductivity values is distinguishable in a down slope direction for about 75 ft from this outlet. Two more conspicuous patterns of anomalously high apparent conductivity values were associated with an exposed and open drain from a nearby septic field and runoff from an animal waste stacking area.

Maine Study Site

The site is located in Cumberland County. Portions of the site were in hayland, recently cultivated, and idle. The idle land adjoins a small drainageway. The drainageway flows from near an animal-waste stacking area. Concerns have been expressed as to the possible discharge of contaminants into the drainage system. The study site is an in area that has been mapped as Buxton silt loam, 3 to 8 percent slopes, (Hedstrom, 1974). The very deep, moderately well drained Buxton soil formed in glaciolacustrine or glaciomarine deposits on coastal lowlands. Buxton soil is a member of the fine, illitic, frigid Dystric Eutrochrepts family.

Field Procedures:

An irregularly shaped 200 by 275-foot grid was established across the study site. The grid interval was 25 feet. Survey flags were inserted in the ground at each grid intersection and served as observation point. This procedure provided 104 observation points.

The relative elevation at 104 observation points was determined with a level and stadia rod. Elevations were tied to a 104.46-foot benchmark. Figure 1 is a three-dimensional surface net diagram of the study area. Relief is about 10 feet. The small stream that flows from near an animal-waste stacking area is shown in Figure 1. A gravel road orthogonally cross this drainageway and forms the western border of the site. The animal waste stacking area is located across this road and to the south and west.

Measurements were taken at each observation point with an EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations. Measurements were also taken at each observation point with an EM31 meter held at hip-height in both the horizontal and vertical dipole orientations.

Table 2 summarizes the apparent conductivity measurements. The apparent conductivity of the upper 0.75 meter (measured with the EM38 meter in the horizontal dipole orientation) averaged 8.5 mS/m with a range of 5.5 to 17.0 mS/m. One-half of the observations had values of apparent conductivity between 7.4 and 9.0 mS/m. The apparent conductivity of the upper 1.5 meters (measured with the EM38 meter in the vertical dipole orientation) averaged 8.3 mS/m with a range of 3.6 to 16.2 mS/m. One-half of the observations had values of apparent conductivity between 6.7 and 8.8 mS/m. The apparent conductivity of the upper 2 meters (measured with the EM31 meter held at hip-height in the horizontal dipole orientation) averaged 15.7 mS/m with a range of 12.0 to 21.0 mS/m. One-half of the observations had values of apparent conductivity between 14.0 and 17.0 mS/m. The apparent conductivity of the upper 5 meters (measured with the EM31 meter at hip-height in the vertical dipole orientation) averaged 19.0 mS/m with a range of 14.0 to 28.0mS/m. One-half of the observations had values of apparent conductivity between 18.0 and 20.0 mS/m. In general, values of apparent conductivity increase with increasing depths of observation.

Table 2
Basic Statistics
EMI Survey
Freeport, Maine, Study Site
(All values are in mS/m)

	AVERAGE	MINIMUM	MAXIMUM	FIRST	MEDIAN	THIRD
EM38H	8.5	5.5	17.0	7.4	8.0	9.0
EM38V	8.3	3.6	16.2	6.7	7.8	8.8
EM31H	15.7	12.0	21.0	14.0	16.0	17.0
EM31V	19.0	14.0	28.0	18.0	19.0	20.0

Figure 7 contains two-dimensional plots of apparent conductivity collected with the EM38 meter. The left-hand plot represents data collected with the EM38 meter in the horizontal dipole orientation. The right-hand plot represents data collected with the EM38 meter in the vertical dipole orientation. The location of the drainageway has been shown in each plot. In each plot, the isoline interval is 3 mS/m. In both plots, spatial patterns do not indicate contamination of the drainageway by waste products from the animal-waste stacking area. Higher values of apparent conductivity can be observed in the extreme southwestern and southeastern corners of the study site. The southwest corner adjoins the gravel road. This area of high apparent conductivity includes the extreme western portion of the drainageway. Higher values of apparent conductivity in the southwest corner could reflect past management practices or the influence of the road itself (spilled or spread chemicals such as road salts). Soils in the southeastern portion of the study site had recently been tilled. It is possible that wastes had been worked into the soil. This process could explain the higher values of apparent conductivity in this portion of the study site. Other spatial patterns seen in Figure 7 are believed to reflect changes in soils or soil properties.

Figure 8 contains two-dimensional plots of apparent conductivity collected with the EM31 meter. The left-hand plot represents data collected with the EM31 meter in the horizontal dipole orientation. The right-hand plot represents data collected with the EM31 meter in the vertical dipole orientation. The location of the drainageway has been shown in each plot. In each plot, the isoline interval is 2 mS/m. Compared with data collected with the EM38 meter, apparent conductivity is higher in the data collected with the EM31 meter.

In both plots appearing in Figure 8, spatial patterns do not indicate contamination of the drainageway by waste products from the animal-waste stacking area. As in the data collected with the EM38 meter, higher values of apparent conductivity can be observed in the extreme southwestern and southeastern corners of the study site. These patterns are believed to reflect use and management, but not the imprint of wastes from the animal-waste stacking area. Other spatial patterns seen in Figure 8 are believed to reflect changes in soils or soil properties.

References

Brune, D. E. and J. A. Doolittle. 1990. Locating lagoon seepage with radar and electromagnetic survey. Environ. Geol. Water Sci. 16:195-207.

Drommerhausen, D. J., D. E. Radcliffe, D. E. Brune, and H. D. Gunter. 1995. Electromagnetic conductivity survey of dairies for groundwater nitrate. J. Environmental Quality, 24: 1083-1091.

Eigenberg, R. A., R. L. Korthals, and J. A. Nienaber. 1998. Geophysical electromagnetic survey methods applied to agricultural waste sites. J. Environmental Quality, 27:215-219.

Hedstrom, G. 1974. Soil Survey of Cumberland Maine. USDA-Soil Conservation Service. U. S. Government Printing Office, Washington, DC.

Geonics Limited. 1998. EM38 ground conductivity meter operating manual. Geonics Ltd., Mississauga, Ontario. 33 pp.

Greenhouse, J. P., and D. D. Slaine. 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2): 47-59.

Kachanoski, R. G., E. G. Gregorich, and I. J. van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

McNeill, J. D. 1980. Electromagnetic terrain conductivity measurements at low induction numbers. Technical Note TN-6. Geonics Ltd., Mississauga, Ontario. 15 p.

Radcliffe, D. E., D. E. Brune, D. J. Drohmerhausen, and H. D. Gunther. 1994. Dairy loafing areas as sources of nitrate in wells. p. 307-313. IN: Environmentally Sound Agriculture; Proceedings of the Second Conference. 20-24 July 1994. American Society of Agricultural Engineers. St. Joseph, MI.

Ranjan, R. S., and T. Karthigesu. 1995. Evaluation of an electromagnetic method for detecting lateral seepage around manure storage lagoons. ASAE Paper 952440. ASAE, St. Joseph, MI.

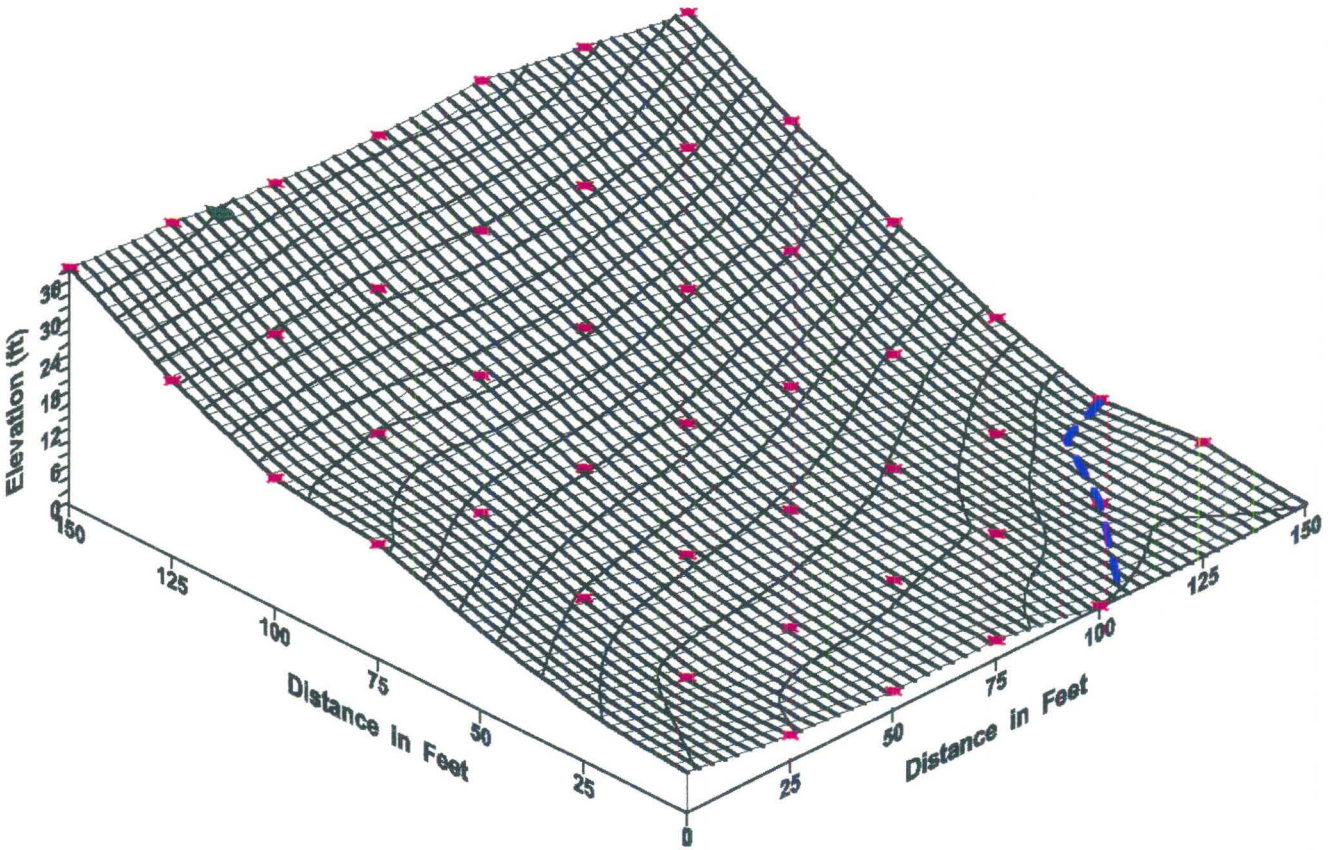
Rhoades, J. D., P. A. Raats, and R. J. Prather. 1976. Effects of liquid-phase electrical conductivity, water content, and surface conductivity on bulk soil electrical conductivity. Soil Sci. Soc. Am. J. 40:651-655.

Sheeham, W. J., 1987. Soil Survey of Windham County, Vermont. USDA-Soil Conservation Service. U. S. Government Printing Office, Washington, DC. 283 p.

Siegrist, R. L. and D. L. Hargett. 1989. Application of surface geophysics for location of buried hazardous waste. Water Management and Research 7:325-335.

Stierman, D. L. and L. C. Ruedisili. 1988. Integrating geophysical and hydrogeological data: An efficient approach to remedial investigations of contaminated ground water. p. 43-57. IN: Collins, A. G. and A. J. Johnson (eds.) Ground water contamination field methods. ASTM STP 963. American Society for Testing Materials, Philadelphia.

EMI TRAINING
VERMONT SITE
TOPOGRAPHY



Observation point

Waste Storage Tank

Figure 1

EMI TRAINING
VERMONT SITE
EM38 METER

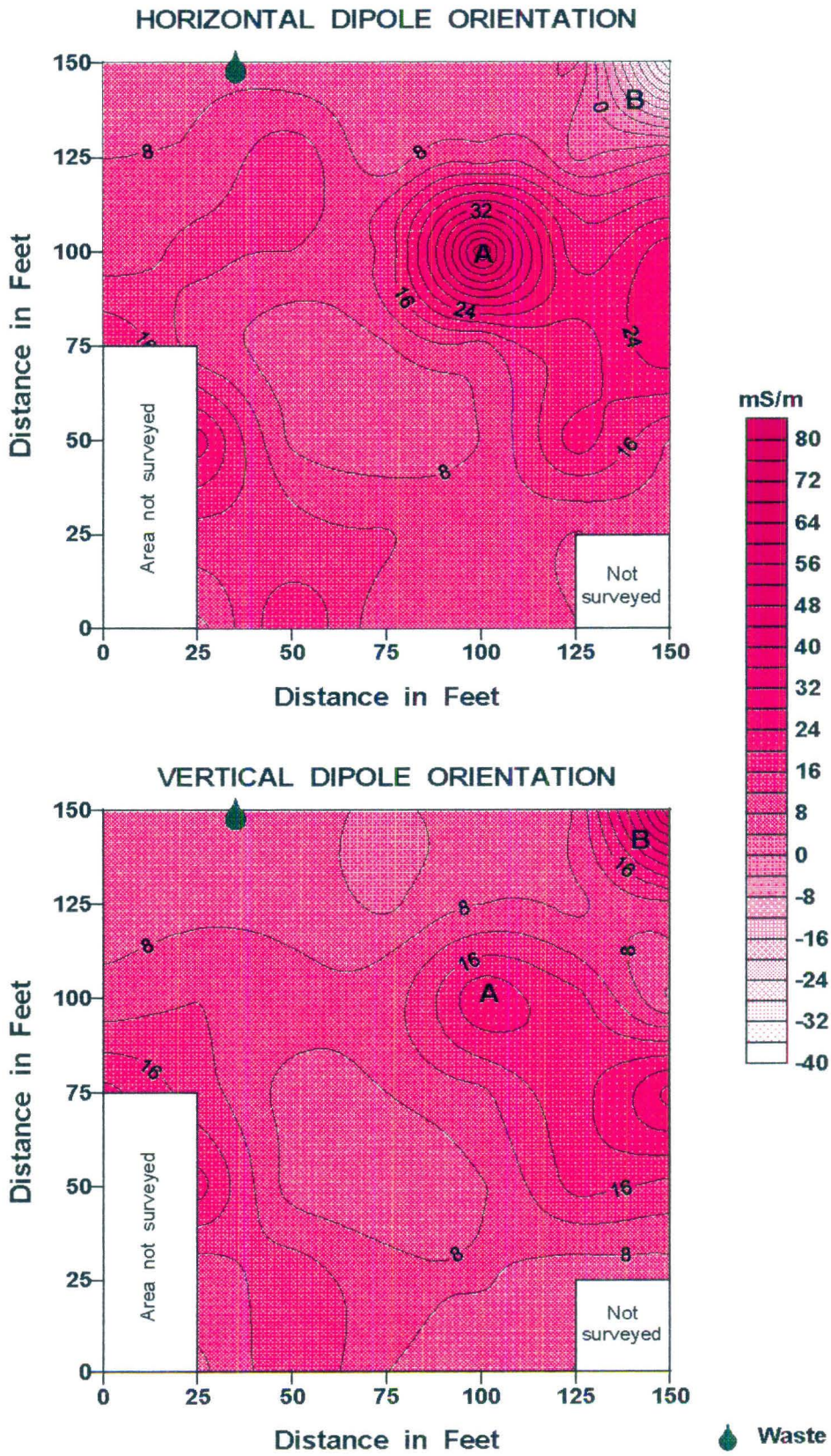
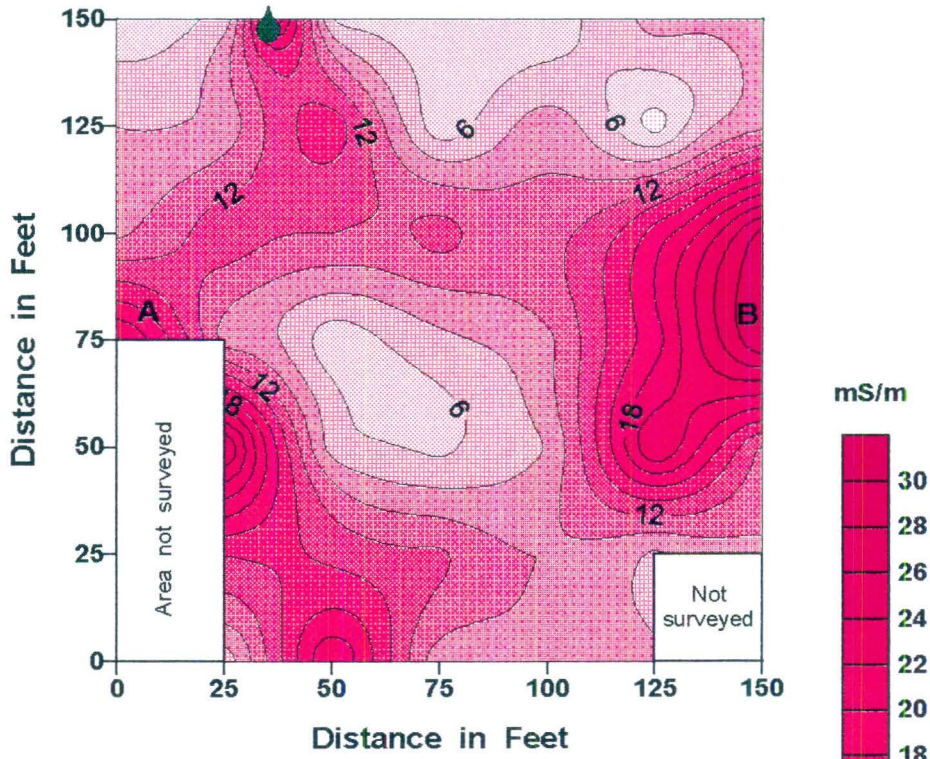


Figure 2

Waste Storage Tank

EMI TRAINING
VERMONT SITE
EM38 METER

HORIZONTAL DIPOLE ORIENTATION



VERTICAL DIPOLE ORIENTATION

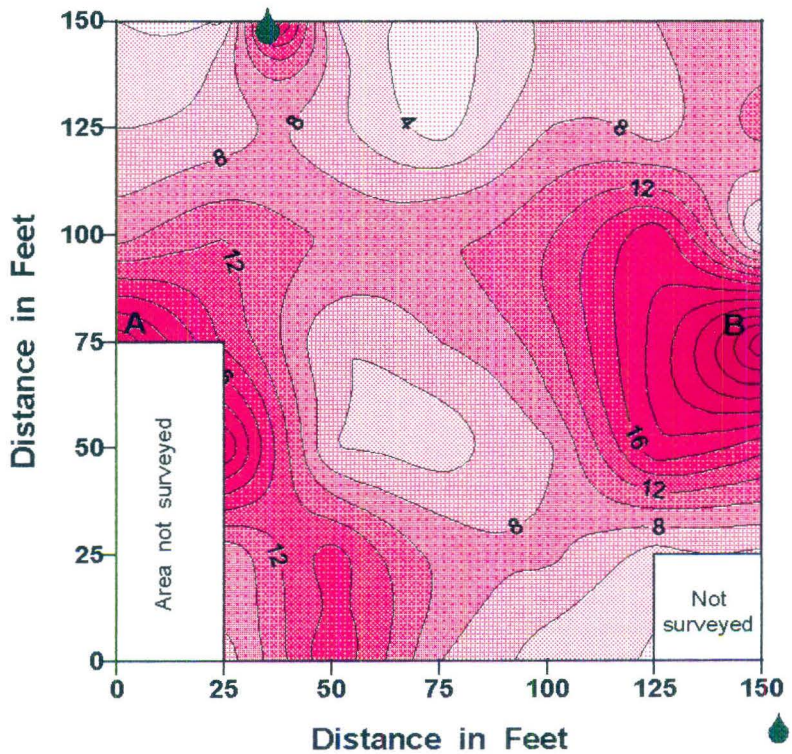
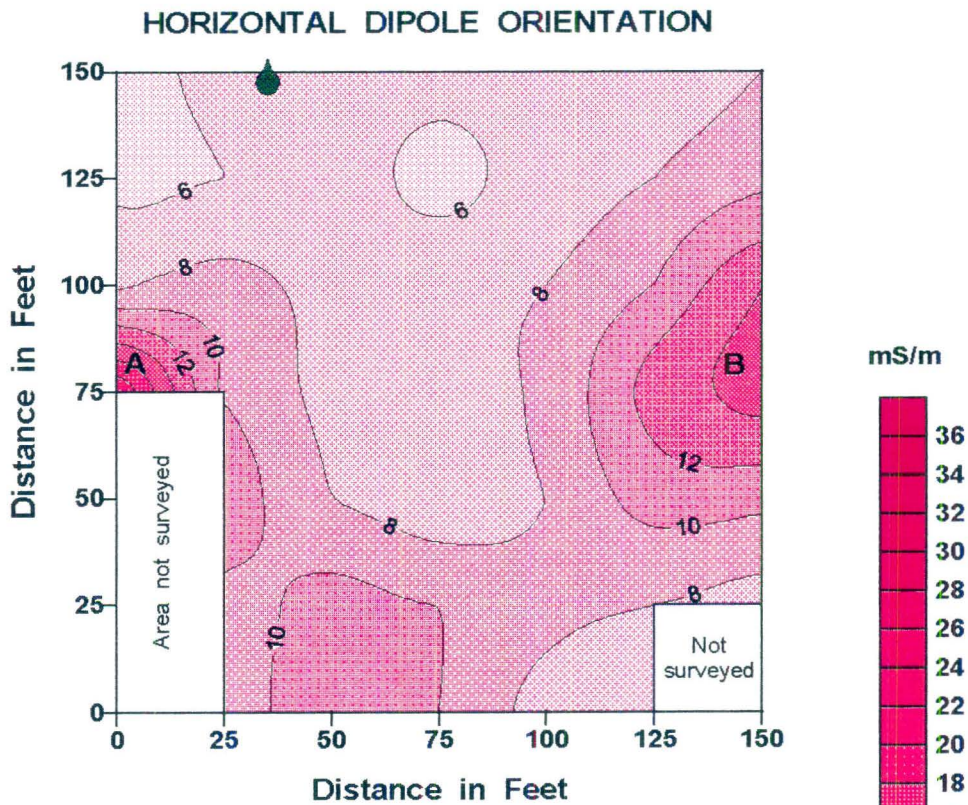


Figure 3

Waste Storage Tank

EMI TRAINING
VERMONT SITE
EM31 METER



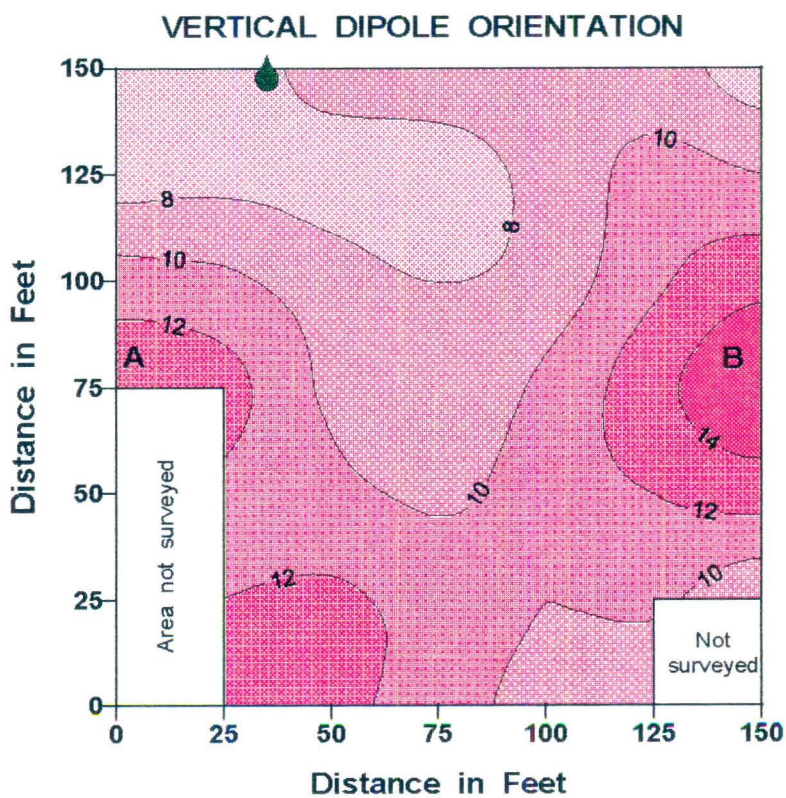


Figure 4

Waste Storage Tank

EMI TRAINING
VERMONT SITE
EM38 METER

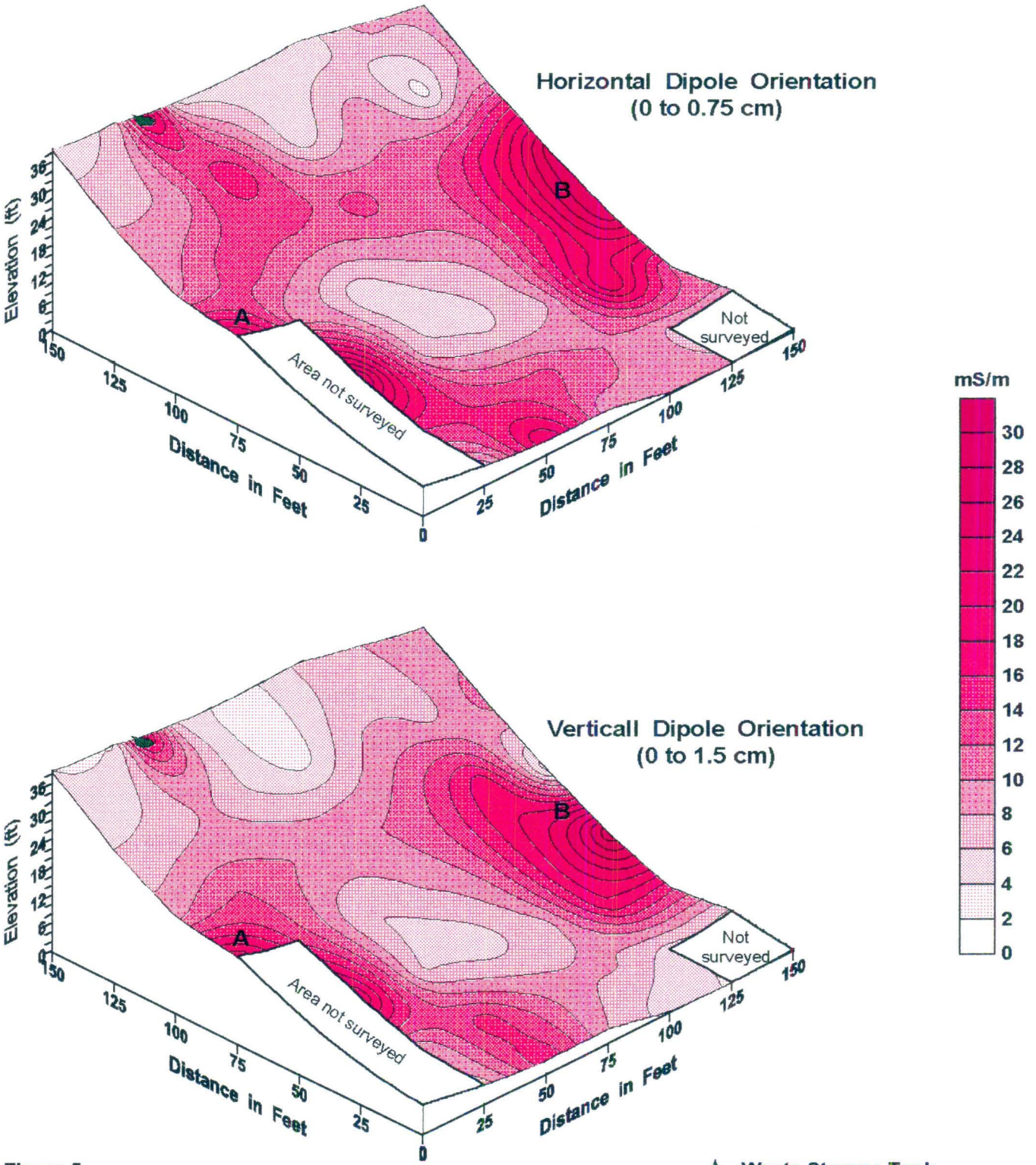


Figure 5

Waste Storage Tank

EMI TRAINING
MAINE SITE
TOPOGRAPHY

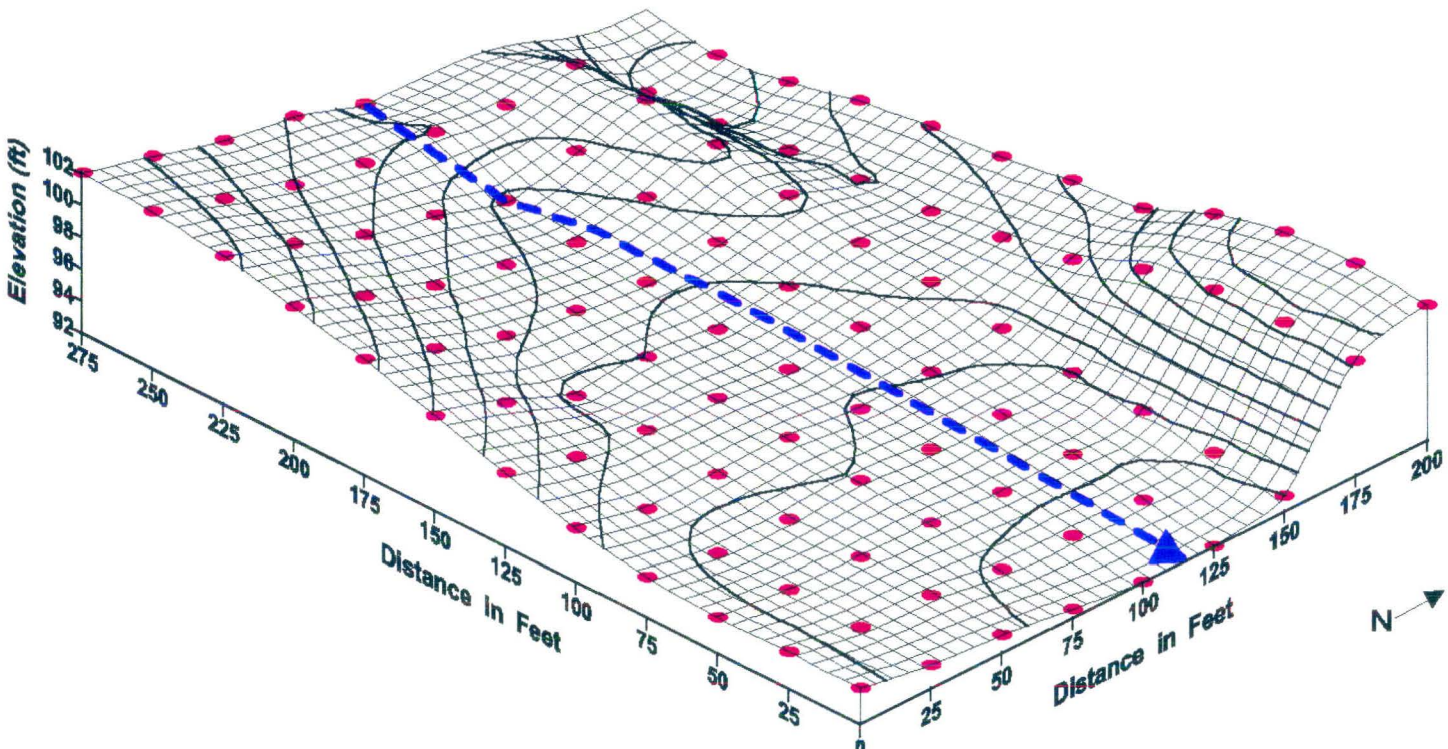


Figure 6

● Observation point

EMI TRAINING
MAINE SITE
EM38 METER

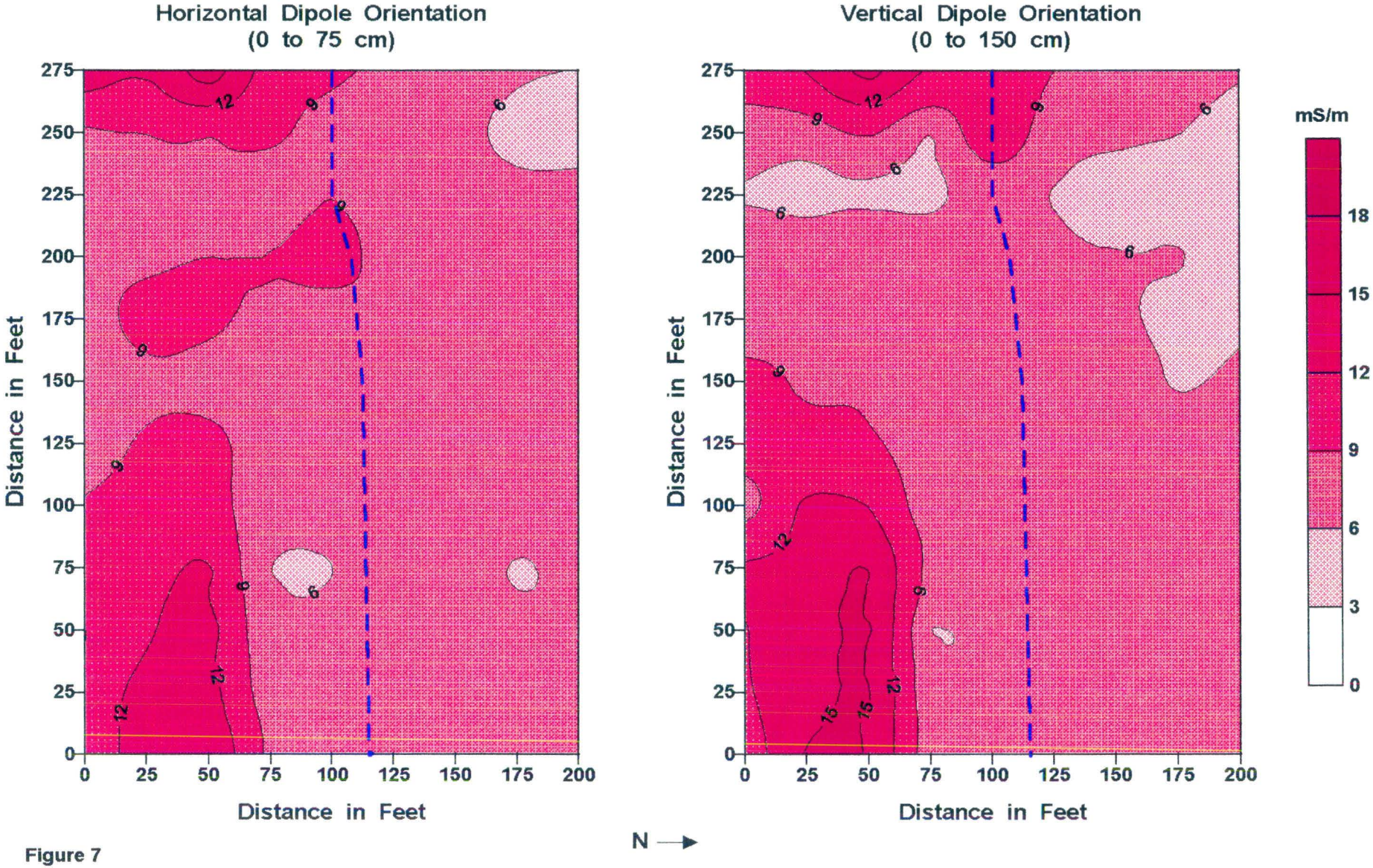


Figure 7